Stratospheric Ozone Loss over the US in Summer:

Recent Advances in the Analysis of the Dynamics and Photochemical Catalytic Mechanisms that Control the Response of O_3 to Storm Induced Convective Injection of Water Vapor and/or Sulfate Addition from Volcanic Eruptions or Climate Engineering

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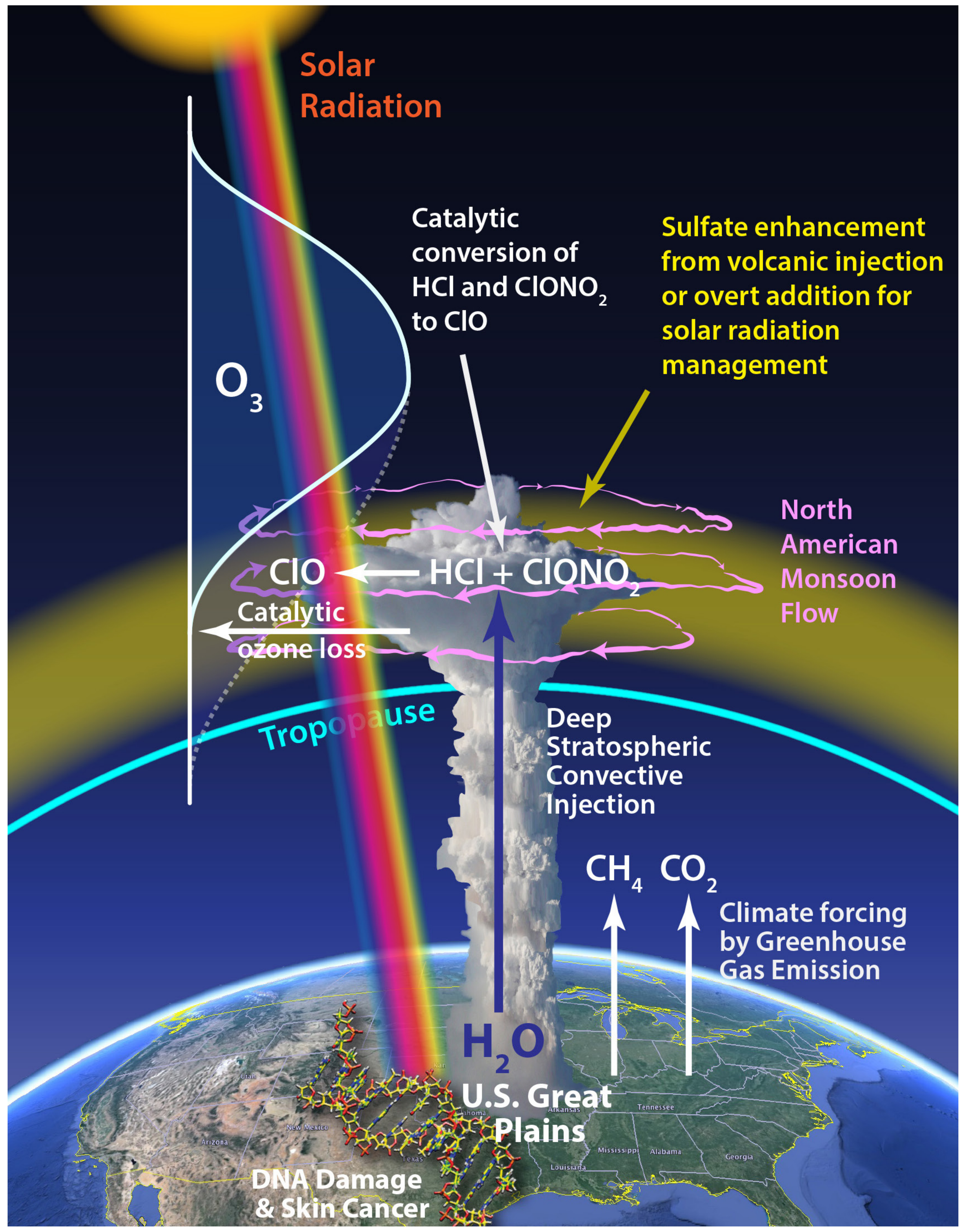
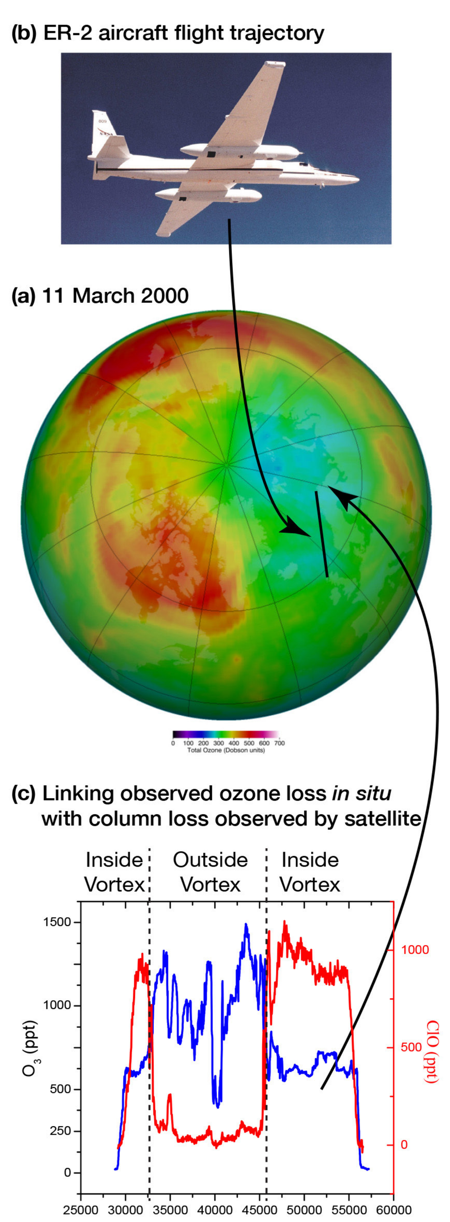


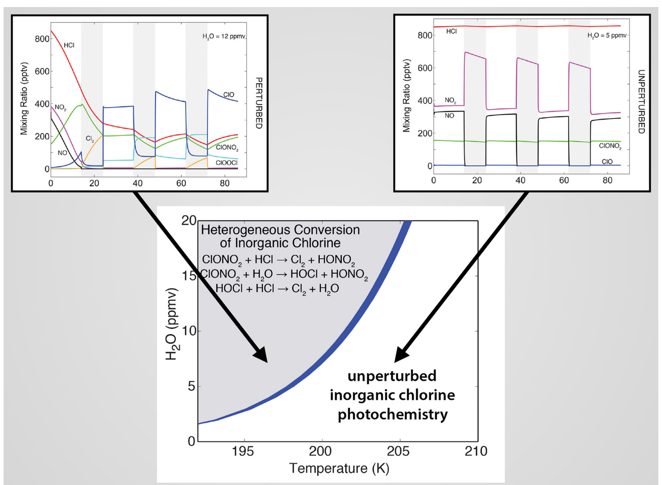
In the context of changes to the structure of the Earth's climate resulting from the release of infrared active gases, most notably CO_2 and CH_4 from fossil fuel extraction, distribution and combustion, consequences to stratospheric ozone over the US in summer are considered in the following segments:

1. Observations of large O_3 loss in the lower stratosphere that set the catalytic coordinate system with respect to dependence on temperature, water vapor mixing ratio, and sulfate loading.
2. New observations that refine the quantitative knowledge of temperatures, gravity wave influence, convective injection heights of water into the stratosphere from the NEXRAD weather radar in the coordinate system of potential temperature, and observations of available inorganic chlorine as a function of potential temperature.
3. Modeling studies using AER 2D calculations in combination with observations of temperature, water vapor convective injection heights, and sulfate loading from the Mt. Pinatubo eruption to calculate the response of the primary rate limiting radicals, catalytic ozone loss rates, impact on the ozone vertical distribution in the lower stratosphere and the resulting fractional decrease in ozone column concentration over the US in summer.
4. The consequences on human health resulting from fractional decreases in ozone column concentration linked to fractional increases in skin cancer incidence in the US.
5. A compendium of scientific questions that remain unanswered.

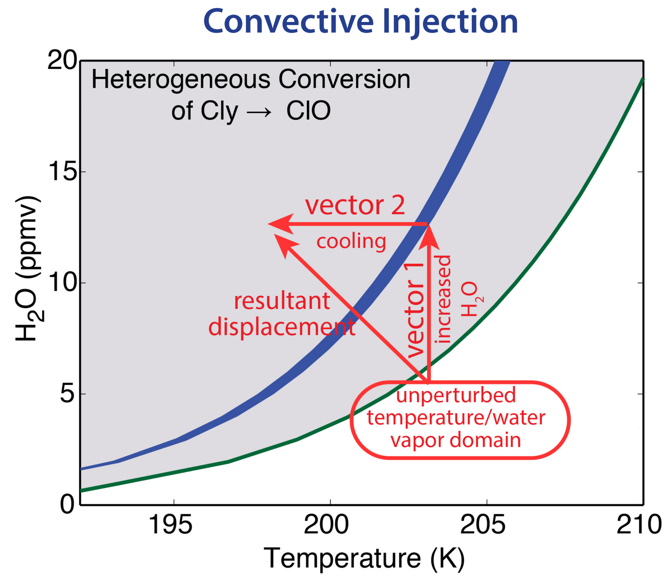
1. Observations of Ozone Loss that Define the Photochemical Coordinate System for Catalytic Ozone Loss

High Latitude Lower Stratosphere

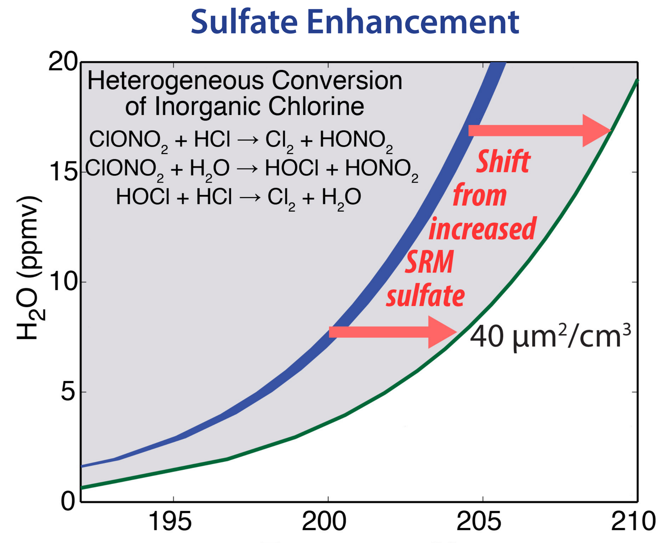




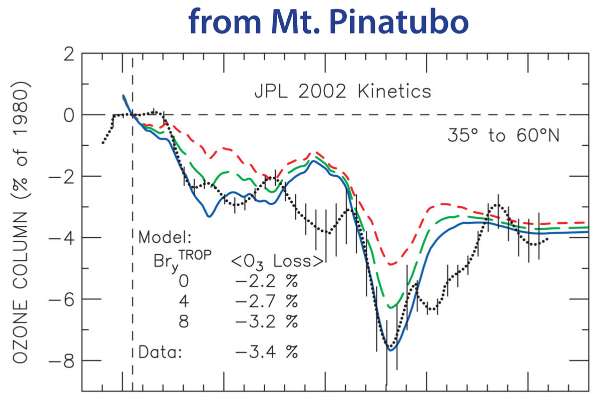
Convective Injection



Sulfate Enhancement



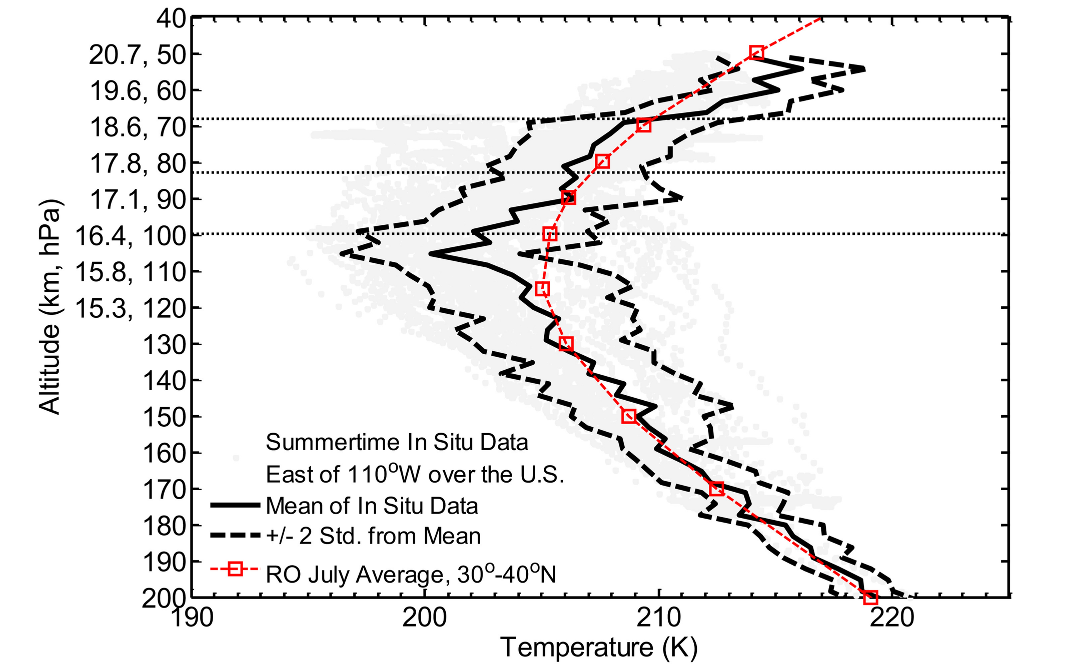
Mid Latitude Lower Stratosphere from Mt. Pinatubo



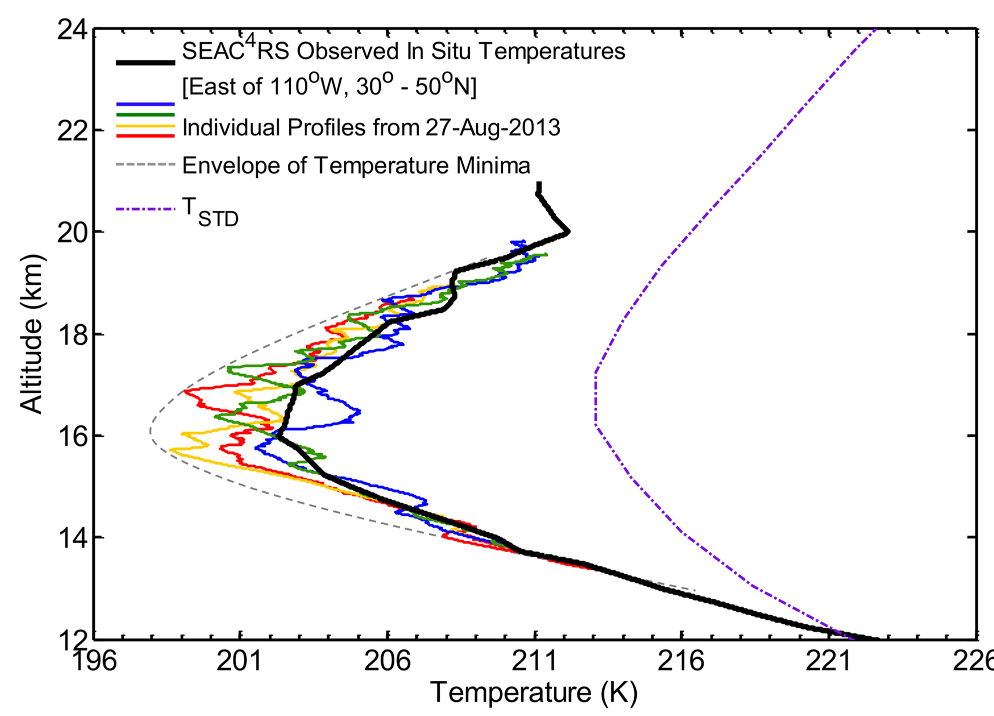
2. New Observations of Temperatures, Gravity Waves, Water Vapor Convective Injection Heights, Inorganic Chlorine, and Cross Calibration of NEXRAD and Cly on θ Surfaces

(A) Temperature

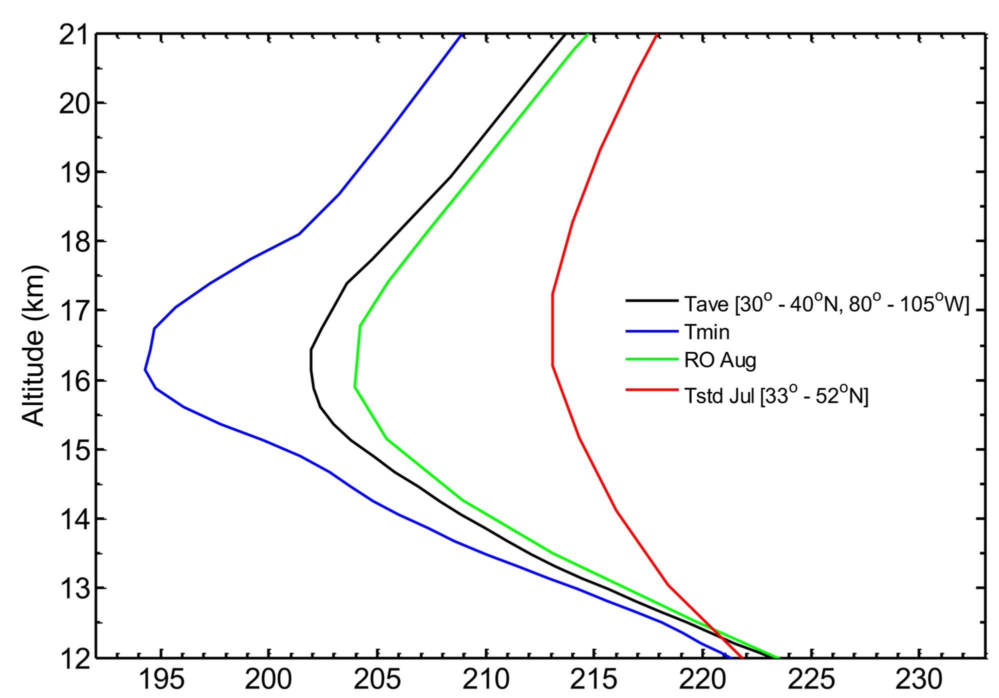
In Situ Temperatures from SEAC⁴RS and Radio Occultation



Gravity Wave Control of Temperatures from SEAC⁴RS

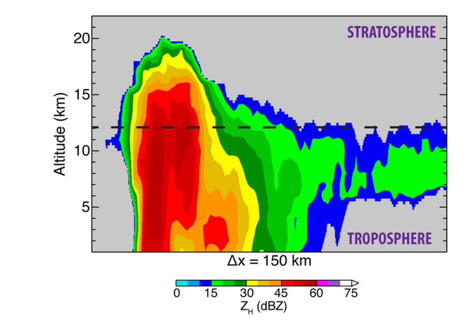


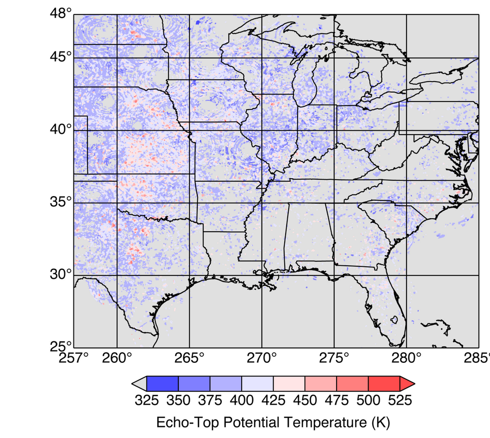
Radio Occultation Temperatures over Central US in Summer Linked to SEAC⁴RS Temperatures and Standard Atmosphere

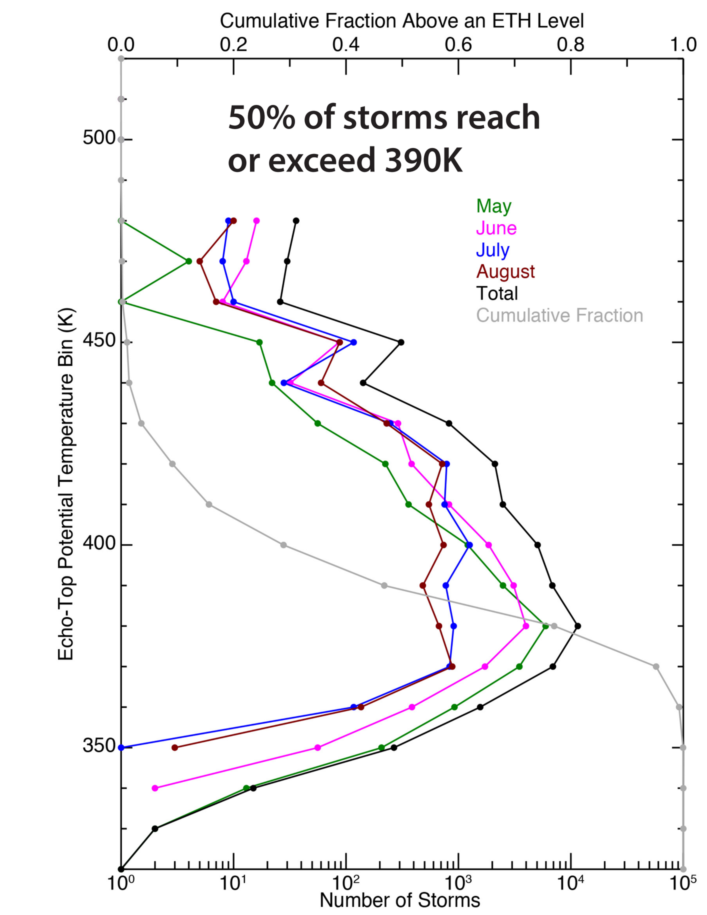


(B) Water Vapor Convective Injection

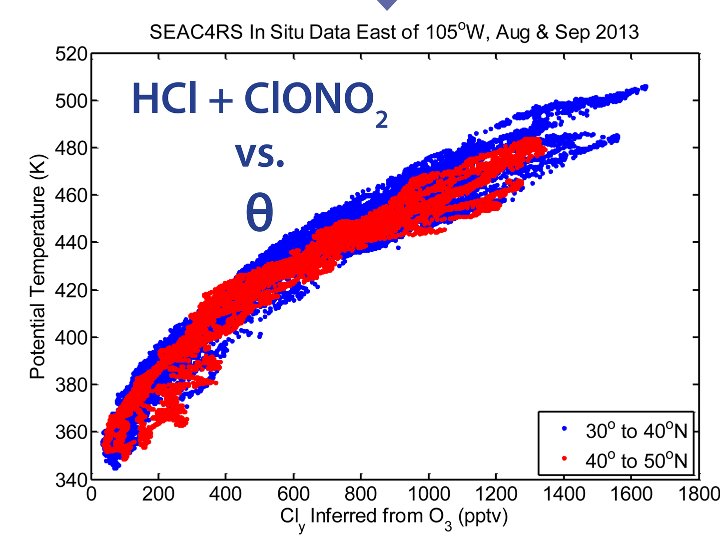
NEXRAD Weather Radar



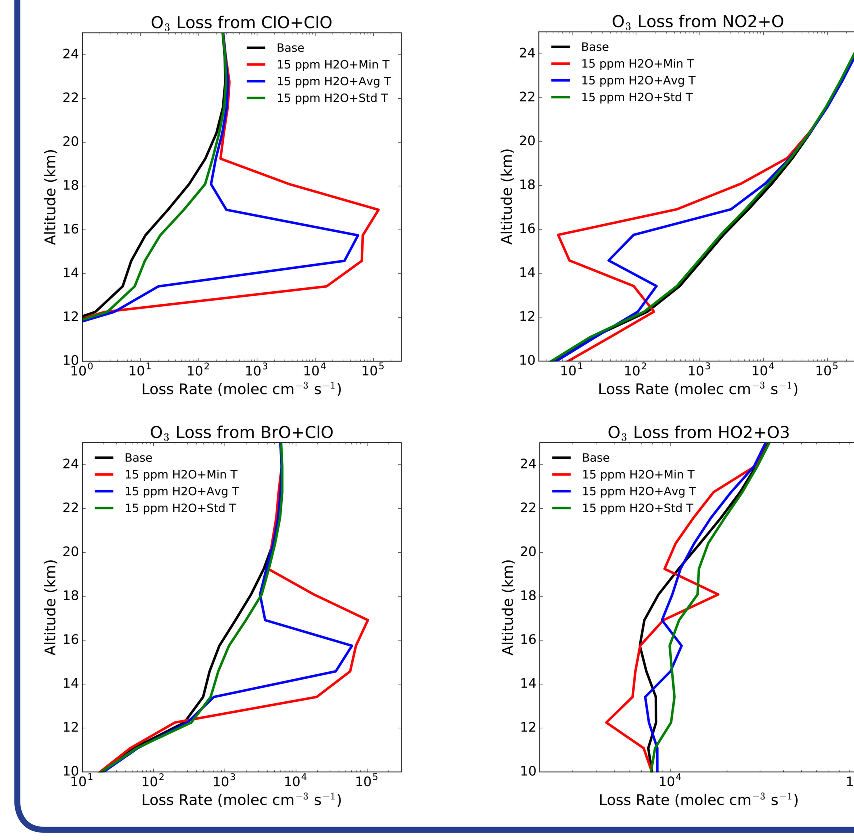


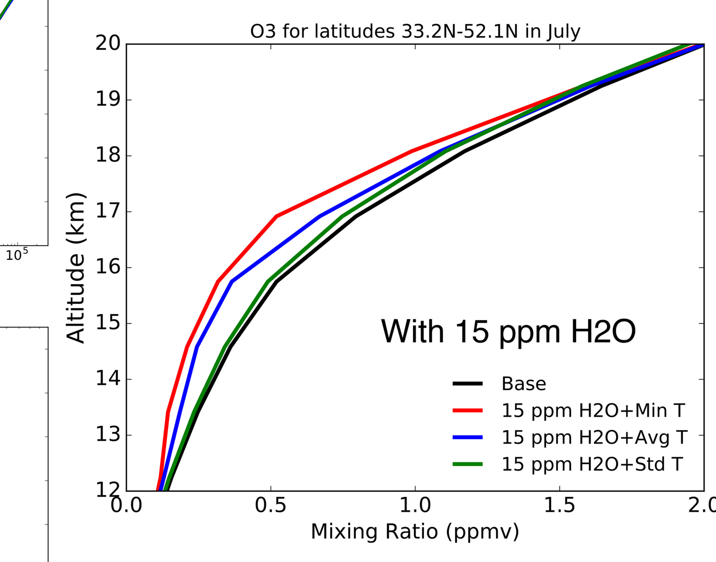


Calibrated against θ

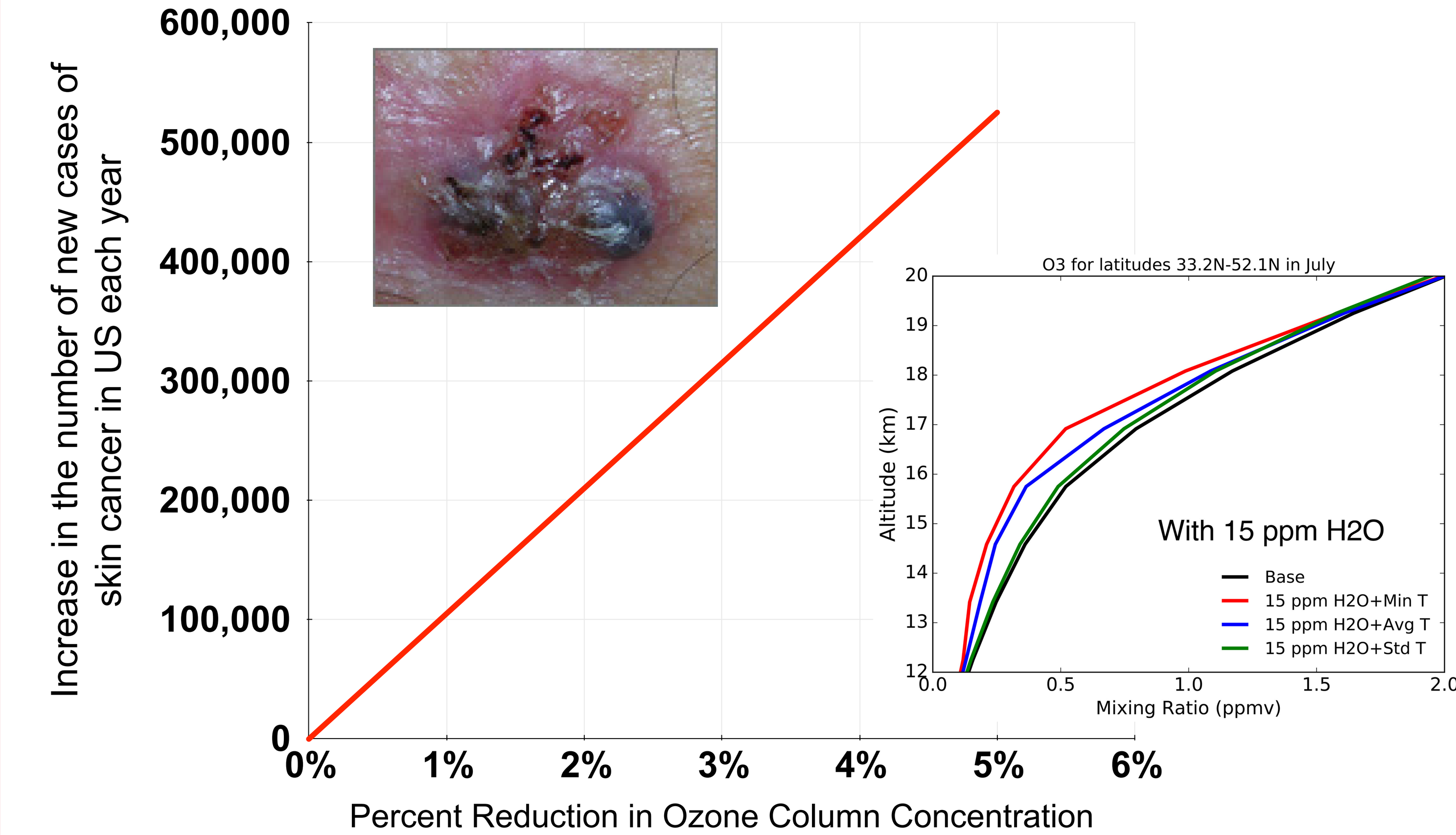


3. AER 2D Model Calculations Using Detailed Temperature Data for the Cases of (a) Convective Injection, (b) Volcanic Injection of Sulfate and (c) Convective Injection into Volcanic Background Sulfate





4. Consequences: Linking Column Ozone Loss to Human Health



5. Summary of the Scientific Issues that Remain Unresolved

1. While simultaneous in situ observations of the catalytic rate limiting radicals ClO, BrO, HO_2, and NO_2 along with HCl, $ClONO_2$, ClOOCl, OH, NO, H_2O and O_3 have been made in the lower stratosphere in the Arctic, this set of observations has never been made over the US in summer. This represents an important shortcoming in the coupling of scientific investigation and public policy.
2. The dominant catalytic radicals ClO, BrO, HO_2, and NO_2 have never been observed within conditions of elevated water vapor, nor have the dominant inorganic chlorine species HCl and $ClONO_2$ been observed under conditions of elevated H_2O or sulfate reactive surface area in the lower stratosphere.
3. While the NEXRAD weather radar network has now established the frequent convective injection of condensed phases of water to altitudes well into the regime of rapidly increasing available inorganic chlorine, over the central US in summer simultaneous in situ observations of H_2O, temperature, sulfate reactive surface area, HCl, $ClONO_2$, ClO and NO_2 have never been made within the injection regions in the hours and days following the convective event. Because of the extremely rapid heterogeneous catalytic conversion of inorganic chlorine to free radical form, this is a major shortcoming in our observational foundation.
4. While significant depletion in the column concentration of ozone over mid-latitudes of the NH following the eruption of Mt. Pinatubo has been established, no in situ observations of the key species HCl, $ClONO_2$, NO_2, ClO, BrO, HO_2 and O_3 have been made to verify the specifics of the large observed ozone loss.
5. Given that the physics underlying the mechanisms responsible for the remarkable depth of stratospheric convective penetration over the US in summer remains unsolved, the response of both the frequency and intensity of those storm systems to increased forcing of the climate by increasing levels of carbon dioxide and methane released as a result of the extraction, distribution and combustion of fossil fuels also remains unsolved.
6. Because the dynamical structure within the domain of the deep stratospheric convective injection has never been dissected by observations with sufficient spatial resolution to diagnose the interaction of the injection field with the background stratospheric structure, the coupling between the genesis of the deep convection in the lower troposphere and the degree to which the dynamics and structure of the lower stratosphere contributes to the ultimate depth of convective penetration remains unsolved.
7. Recent research defining the large dynamic range in chlorine and bromine content of volcanic eruptions underscores the imperative to establish a quantitative understanding of the potential impact of combinations of volcanic eruptions with varying degrees of halogen content with sulfate in combination with deep stratospheric convective injection over the US in summer.
8. What is the mechanistic impact of UV radiation in the stratosphere on the heterogeneous catalytic conversion of HCl + $ClONO_2$ to free radical form?